May 14, 2013

Orbital Debris Assessment for
The CubeSats on the
CRS SpX-3 / ELaNa-5 Mission
per NASA-STD 8719.14A

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. *P-POD Status SpX-3 Agreement History* (Orbital Information) , ISS_CM_019 Rev 01/2011
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2nd ed. Northbrook, IL, Underwriters Laboratories, 2005
I. Opiela, John. "RE: DAS 2.0 Orbital Lifetime Inquiry" April 5, 2013. E-mail.

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa-5 auxiliary mission launching in conjunction with the SpX-3 primary payload. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the launch vehicle compliance assessment and are not presented here.

The following table summarizes the compliance status of the ELaNa-5 auxiliary payload mission flown on SpX-3. The five CubeSats, both manifested and back-ups, comprising the ELaNa-5 mission are fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Compliant	Lifetime of debris is days
4.3-1b	Compliant	Lifetime of debris is days
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-2	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	Worst case lifetime 0.2yrs
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether release under ELaNa-5 mission

Section 1: Program Management and Mission Overview

The ELaNa-5 mission is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

All-STAR/THEIA: Christoper Koehler, Principle Investigator;
Jessica Brown, Project Manager

PhoneSat v2.5: Jasper Wolf, Project Manager

TSAT: Dr. Hank Voss, Principle Investigator;
Jeff Dailey, Project Manager

KickSat: Mason Peck, Principle Investigator;
Zachary Manchester, Project Manager

SporeSat: Andres Martinez, Project Manager

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	7/1/12
CubeSat Build, Test, and Integration	July 2012 to July 2013
MRR	7/23/13
CubeSat Delivery/integration at Cal Poly	9/16/12
P-POD Integration into LV	10/28/13
Launch	12/9/13

Figure 1: Program Milestone Schedule

The ELaNa-5 mission will deploy 5 pico-satellites (or CubeSats) as a secondary payload on the mission. The CubeSat slotted position is identified in Table 2: ELaNa-5 CubeSats. The ELaNa-5 manifest includes: ALL-STAR/THEIA, PhoneSat v2.5, TSAT, KickSat, SporeSat.

Each CubeSat ranges in sizes from a 10 cm cube to 10 cm x 10cm x 30 cm, with masses from about 1 kg to 5.3 kg total. The CubeSats have been designed and built by educational institutes and government agencies; each has their own mission goals and objectives.

The ELaNa-5 mission will be launched as an auxiliary payload on the SpX-3 mission on a Falcon 9 launch vehicle from Cape Canaveral Air Force Station. The current launch date is in December 2013. The five CubeSats will be ejected from a PPOD carrier attached to the launch vehicle, placing the CubeSats in an orbit approximately 325 X 325 km at inclination of 51.6 deg (ref. (c)).

Section 2: Spacecraft Description

There are five CubeSats flying on the ELaNa-5 Mission. They will be deployed out of four PPODs, as shown in Table 2: ELaNa-5 CubeSats below.

Table 2: ELaNa-5 CubeSats

PPOD Slot	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
1	1	3U (10 cm X 10 cm X 30 cm)	ALL-STAR/THEIA	3.97
3A 3B	2	1U (10 cm X 10 cm X 10 cm) 2U (10 cm X 10 cm X 20 cm)	PhoneSat v2.5 TSAT	1.12 2.8
4	1	1U (10 cm X 10 cm X 30 cm)	KickSat	3.5
2	1	1U (10 cm X 10 cm X 30 cm)	SporeSat	5.3

The following subsections contain descriptions of these five CubeSats.

TSAT CubeSat Description
Taylor University – 2U

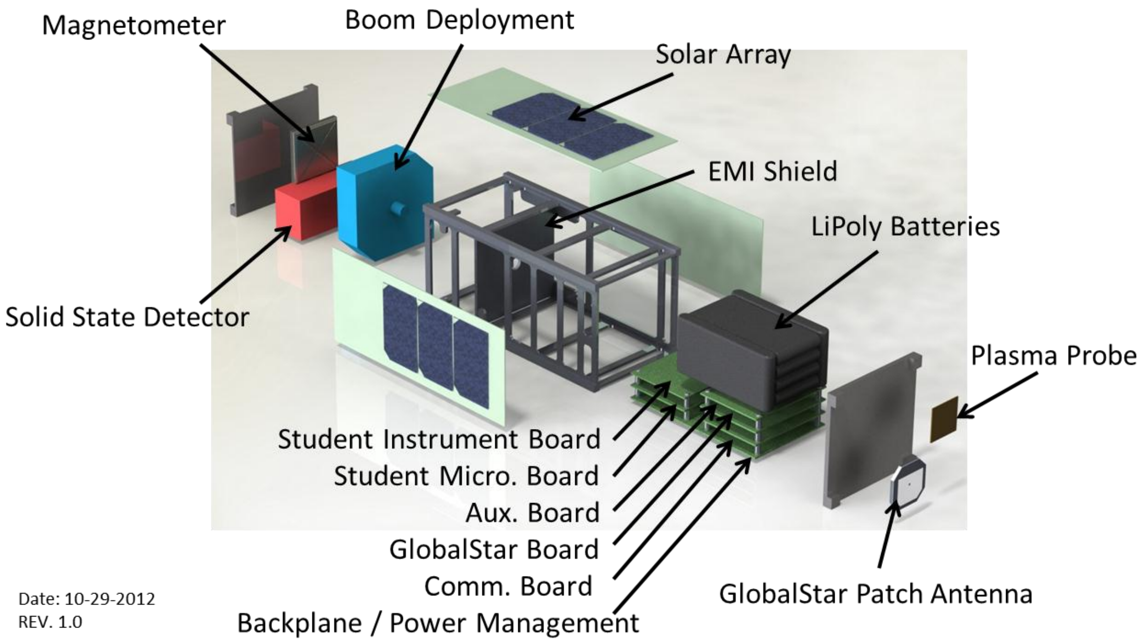


Figure 2: TSAT CubeSat Description

The primary mission of TSAT is to demonstrate a global GlobalStar CubeSat link, undergraduate ABET Capstone education, and *in situ* Ionospheric plasma density measurements for operation in the Extremely Low-Earth Orbit (ELEO) region of space. Understanding the Sun Earth connection below 250km is critical to our understanding of the upper atmosphere and validation of ionospheric models. The student sensor bay on TSAT includes distinct instrumentation to measure fields and particles in the relatively unexplored ELEO region.

Once ejected from the P-POD power management comes online after 5 minutes. 45 minutes after ejection the GlobalStar communications link is powered on and system status data is transmitted. Once the onboard timer reads 50 minutes the deployment module powers up and deploys the VLF booms. Boom status data is sent via Iridum 10 minutes after deployment commences. 65 minutes after ejection the student Micro and Instrument modules power up. As the timer hits 70 minutes after ejection the CubeSat begins operation mode.

TSAT structure is made of 6061-T6 aluminum. Internal and external materials used are, standard electrical components, Printed circuit boards, Stainless steel hardware and solar cells. The Iridium radio uses a 25mm x 25mm ceramic patch antenna.

There are no hazardous materials used on TSAT.

The power system consists of six Li-Poly batteries at 8.1V / 3000mA with a total power of 18Ah available to the system. A built in protection module on each pack for over/under charge and short circuit. The Li-Poly batteries carry the UL-listing number BBCV2.MH29381 and the protection circuit model 32005.

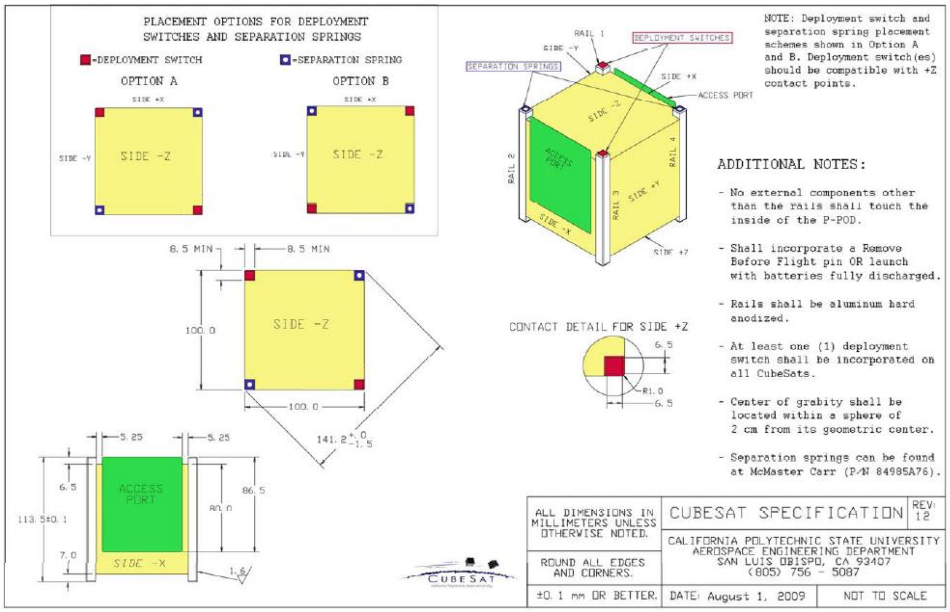
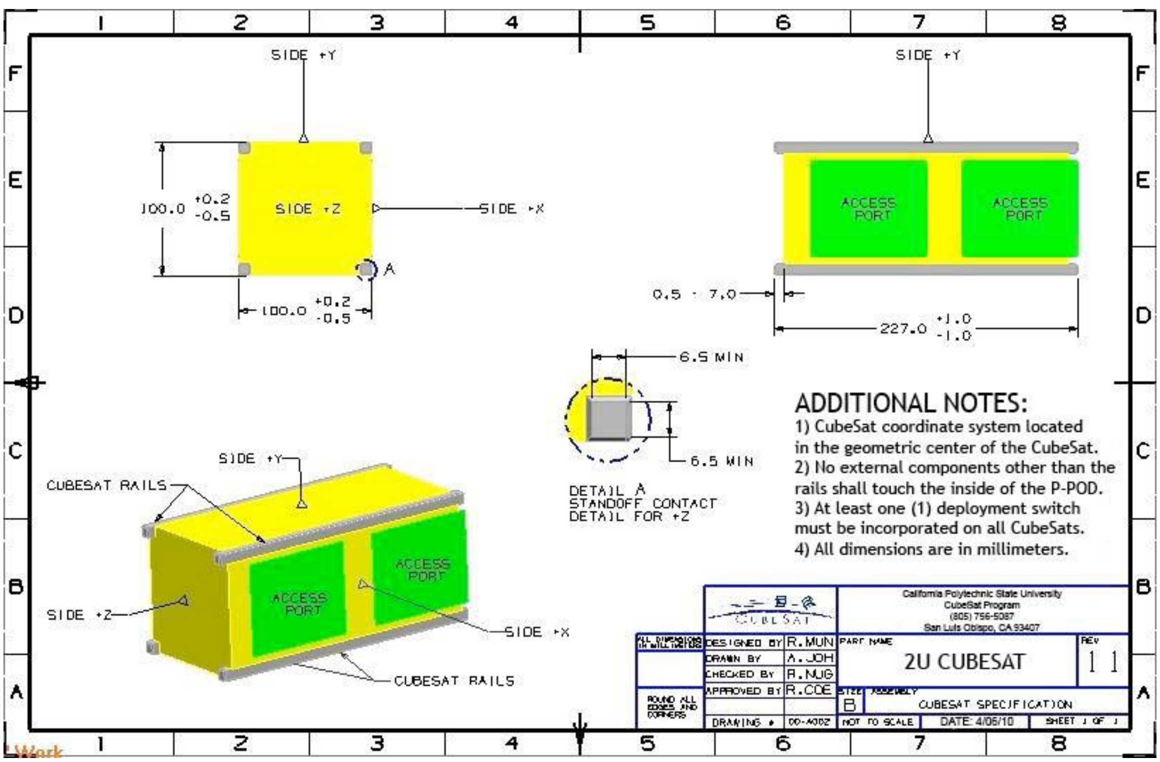


Figure 3: 1U CubeSat Specification



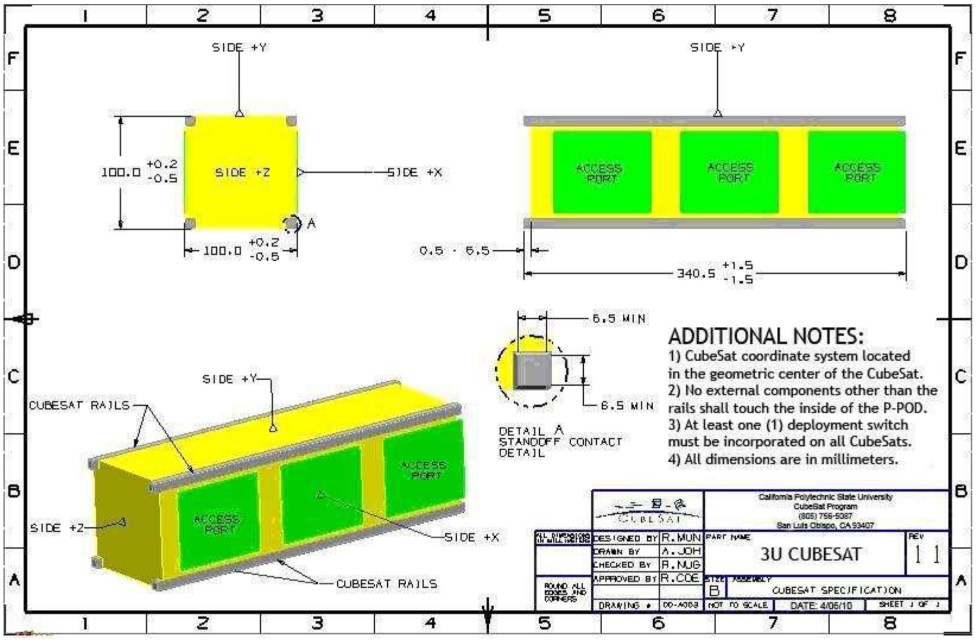


Figure 4: 3U CubeSat Specification

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

Section 3 provides rationale/necessity for release of each object, time of release of each object relative to launch vehicle separation, release velocity of each object with respect to CubeSat, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No releases are planned on the TSAT mission therefore this section is not applicable.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

Note: This entire section applies to all five of the CubeSats on the SpX-3/ELaNa-5 mission.

Malfunction of lithium ion or lithium polymer batteries and/or associated control circuitry has been identified as a potential cause for spacecraft breakup during deployment and mission operations.

While no passivation of batteries will be attempted, natural degradation of the solar cell and battery properties will occur over the post mission period, which may be as long as 0.2 years. These conditions pose a possible increased chance of undesired battery energy release. The battery capacity for storage will degrade over time, possibly leading to changes in the acceptable charge rate for the cells. Individual cells may also change properties at different rates due to time degradation and temperature changes. The control circuit may also malfunction as a result of exposure to the space environment over long periods of time. The cell pressure relief vents could be blocked by small contaminants. Any of these individual or combined effects may theoretically cause an electro-chemical reaction that result in rapid energy release in the form of combustion.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the ELaNa-5 mission.

Section 4 asks for a list of components, which shall be passivated at End of Mission (EOM), as well as the method of passivation and description of the components, which cannot be passivated. No passivation of components is planned at the End of Mission for any of the ELaNa-5 CubeSats.

Since the batteries used do not present a debris generation hazard even in the event of rapid energy release (see assessment directly below), passivation of the batteries is not necessary in order to meet the requirement 4.4-2 (56450) for passivation of energy sources "to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft." Because passivation is not necessary, and in the interest of not increasing the complexity of the CubeSats, there was no need to add this capability to their electrical power generation and storage systems.
Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-2 shows that the ELaNa-5 CubeSats are compliant. Requirements 4.4-3 and 4.4-4, addressing intentional break-ups are not applicable.

The following addresses requirement 4.4-2. The CubeSats that have been selected to fly on the SpX-3 mission have not been designed to disconnect their onboard storage energy devices (lithium ion and lithium polymer batteries). However, the CubeSats batteries still meet Req. 56450 by virtue of the fact that they cannot "cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft".

Table 3: ELaNa-5 CubeSat Cells

CubeSat	Technology	Manufactor	Model	UL Listing Number
TSAT	Lithium Polymer	YOKU Energy	Polypower 4000mAh	MH29381

The batteries are all consumer-oriented devices. All battery cells have been recognized as Underwriters Laboratories (UL) tested and approved. Furthermore, safety devices incorporated in these batteries include pressure release valves, over current charge protection and over current discharge protection.

The fact that these batteries are UL recognized indicates that they have passed the UL standard testing procedures that characterize their explosive potential. Of particular concern to NASA Req. 56450 is UL Standard 1642, which specifically deals with the testing of lithium batteries. Section 20 Projectile Test of UL 1642 (ref. (e)) subjects the test battery to heat by flame while within an aluminum and steel wire mesh octagonal box, "[where the test battery] shall remain on the screen until it explodes or the cell or battery has ignited and burned out" (UL 1642 20.5). To pass the test, "no part of an exploding cell or battery shall penetrate the wire screen such that some or all of the cell or battery protrudes through the screen" (UL 1642 20.1).

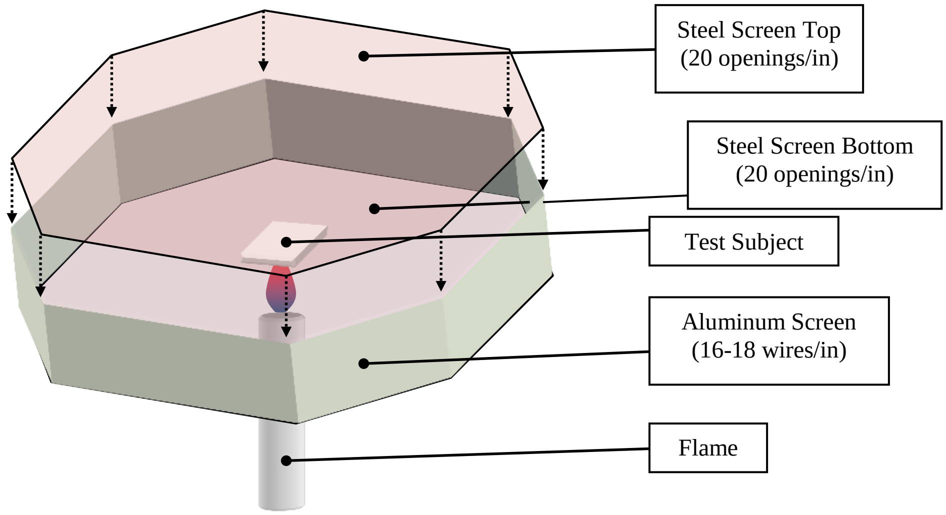


Figure 5: Underwriters Laboratory Explosion Test Apparatus

The batteries being launched via CubeSat will experience conditions on orbit that are generally much less severe that those seen during the UL test. While the source of failure would not be external heat on orbit, analysis of the expected mission thermal environment performed by NASA LSP Flight Analysis Division shows that given the very low (<=41.44 W-hr, maximum for PhoneSat) power dissipation for CubeSats, the batteries will be exposed to a maximum temperature that is well below their 212^{o}F safe operation limit (ref. (f)). It is unlikely but possible that the continual charging with 2 to 6 W of average power from the solar panels over an orbital life span greater than 2 years may expose the two to four batteries (per CubeSat) to overcharging which could cause similar heat to be generated internally. Through the UL testing, it has been shown that these batteries do not cause an explosion that would cause a fragmentation of the spacecraft.

A NASA Glenn Research Center guideline entitled Guidelines on Lithium-ion Battery Use in Space Applications (ref. (d)) explains that the hazards of Li-Ion cells in an overcharge situation result in the breakdown of the electrolyte found in Li-ion cells causing an increase in internal pressure, formation of flammable organic solvents, and the release of oxygen from the metal oxide structure. From a structural point of view a battery in an overcharge situation can expect breakage of cases, seals, mounting provisions, and internal components. The end result could be “unconstrained movement of the battery” (ref. (d), pg 13). This document clearly indicates that only battery deformation and the escape of combustible gasses will be seen in an overcharging situation, providing further support to the conclusion that CubeSat fragmentation due to explosion is not a credible scenario for this application. It is important to note that the NASA guide to Li-ion batteries makes no mention of these batteries causing explosions of any magnitude whatsoever.

Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

The largest mean cross sectional area (CSA) among the five CubeSats is that of the ALL-STAR/THEIA CubeSat with exo-bus and solar panels deployed (maximum wingspan of 31.9 cm in the X and Y axis with a total length of 59.4 cm):

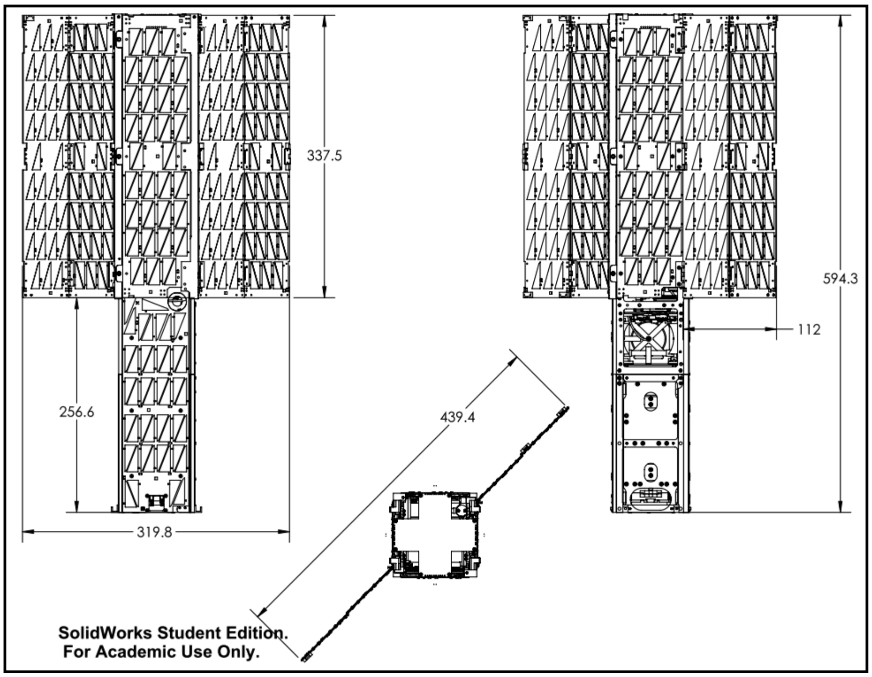


Figure 6: ALL-STAR / THEIA deployed configuration

$$\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\boldsymbol{4}} = \frac{[\boldsymbol{2} * (\boldsymbol{w} * \boldsymbol{l}) + \boldsymbol{4} * (\boldsymbol{w} * \boldsymbol{h})]}{\boldsymbol{4}}$$

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\boldsymbol{Mean\ CSA} = \frac{(\boldsymbol{A_{max}} + \boldsymbol{A_1} + \boldsymbol{A_1})}{\boldsymbol{2}}$$

Equation 2: Mean Cross Sectional Area for Complex Objects

All CubeSats evaluated for this ODAR are stowed in a convex configuration, indicating there are no elements of the CubeSats obscuring another element of the same CubeSats from view. Thus, mean CSA for all stowed CubeSats was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the P-POD and deployables have been extended Equation 2 is utilized to determine the mean CSA. A_{max} is identified as the view that yields the maximum cross-sectional area. A_1 and A_2 are the two cross-sectional areas orthogonal to A_{max}. Refer to Appendix A for dimensions used in these calculations

The ALL-STAR/THEIA orbit at deployment is 325 km apogee altitude by 325 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass (3.97 kg) ratio of 0.0346 m^2/kg, DAS yields 0.1 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. Even with the variation in CubeSat design and orbital lifetime ELaNa-5 CubeSats see an average of $10^{-9.2}$ probability of collision. ALL-STAR/THEIA in the deployed configuration sees the highest probability of collision of $10^{-8.4}$. Table 4 below provides complete results.

Table 4: CubeSat Orbital Lifetime & Collision Probability

	CubeSat			**TSAT**		
	Mass			2.8		
Stowed	**Mean C/S Area (m^2)**			0.0214		
	Area-to Mass (m^2/kg)			0.0076		
	Orbital Lifetime (yrs)			0.2		
	Probability of collision (10^X)			-9.7		
Deployed	**Mean C/S Area (m^2)**			0.0277		
	Area-to Mass (m^2/kg)			0.0099		
	Orbital Lifetime (yrs)			0.1		
	Probability of collision (10^X)			-9.4		

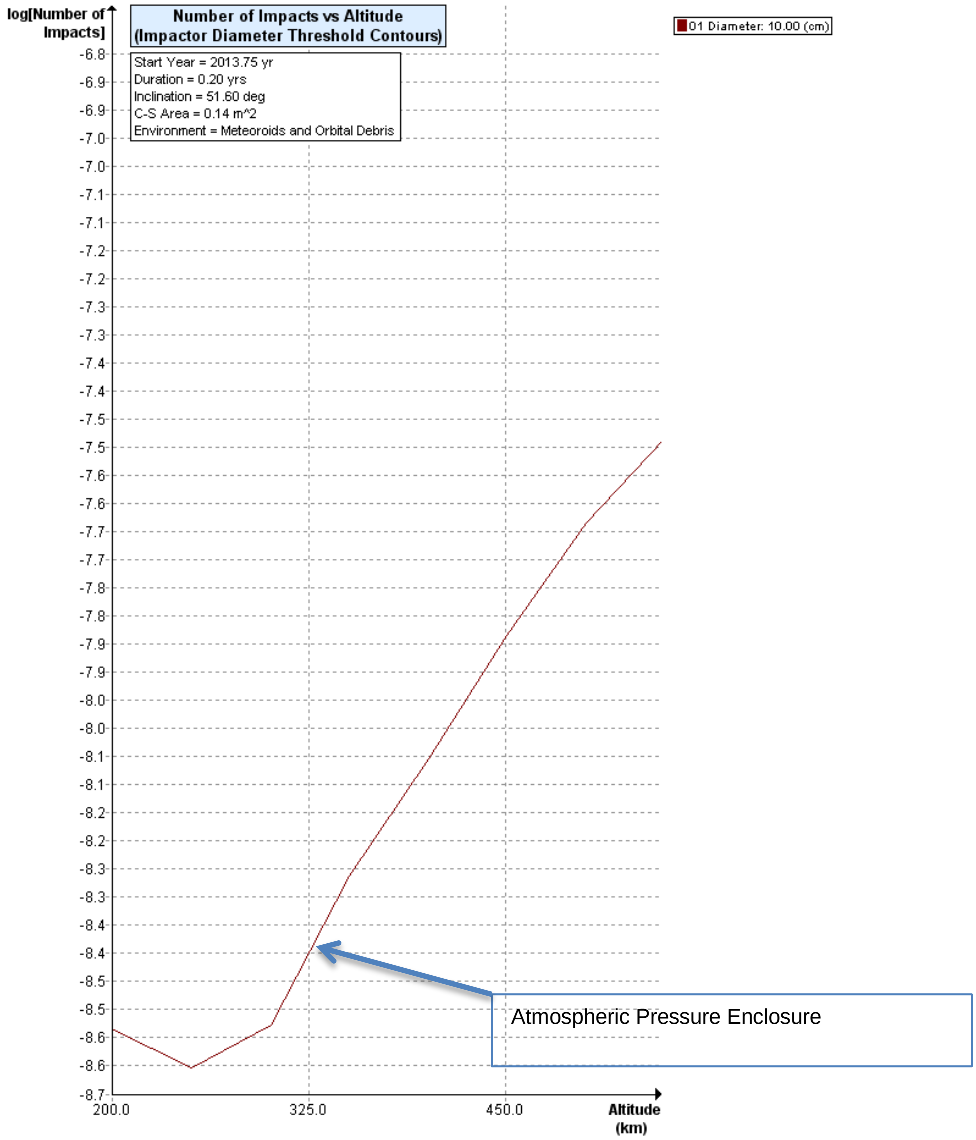


Figure 7: Highest Risk of Orbit Collision vs. Altitude (ALL-STAR/THEIA Deployed)

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

The probability of any ELaNa-5 spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than $10^{-8.4}$, for any configuration. This satisfies the 0.001 (10^{-6}) maximum probability requirement 4.5-1.

Since the CubeSats have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows ELaNa-5 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

All ELaNa-5 spacecraft will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish postmission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal among the CubeSats finds TSAT in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}/_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area-to-Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

Equation 3: Area to Mass

$$\frac{0.0214m^2}{2.8\ kg} = \ 0.0076\frac{m^2}{kg}$$

TSAT has the smallest Area-to-Mass ratio and as a result will have the longest orbital lifetime. The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS 2.0.2 Orbital Lifetime Calculations:</u>

DAS inputs are: 325 km maximum perigee X 325 km maximum apogee altitudes with an inclination of 51.6 degrees at deployment in the year 2013. An area to mass ratio of 0.0076 m^2/kg for the TSAT CubeSat was imputed. DAS 2.0.2 yields a 0.2 year orbit lifetime for TSAT in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 4**.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on ELaNa-5 was performed. The assessment used DAS 2.0, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to meet the human casualty requirement through a bounding DAS analysis of the highest temperature components, generally stainless steel (1500°C). A component of similar dimensions and possessing a melting temperature between 1000 °C and 1500°C, can be expected to posses as negligible risk similar to stainless steel components. Probability of human casualty was calculated if a component exceeded 15J of energy upon reentry. See Table 5.

The five CubeSats of the ELaNa-5 mission all comply with Requirement 4.7-1, to have less than 1:10,000 risk of human casualty.

ALL-STAR/THEIA has multiple components of high temperature Invar material. These survive reentry with more than 15J of energy. However, the risk of human casualty for all pieces of ALL-STAR/THEIA does not exceed 1:10,000 probability (ALL-STAR/THEIA has 1:47,100 probability).

PhoneSat has two large components that survive reentry but have less than 15J of energy, which satisfies the requirement. SporeSat has fasteners constructed out of titanium that have essentially zero joules of energy upon reaching the Earth's surface.

The majority of high temperature components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have less than 15 joules of kinetic energy. No high temperature component will pose a risk to human casualty as defined by the Range Commander's Council (ref. (g)).

As documented in, Table 5: ELaNa-5 Survivability DAS Analysis, and Appendix A-E, all CubeSats launching under the ELaNa-5 mission are conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

See Appendix for a complete accounting of the survivability of all CubeSat components.

Table 5: ELaNa-5 Survivability DAS Analysis

CubeSat	ELaNa-5 Stainless Steel Components	Mass (g)	Length / Diameter (cm)	Widt h (cm)	Height (cm)		Demise Alt (km)	KE (J)
TSAT	Sep Switches	8.0	0.45	1.05	0.00		76.4	0
TSAT	Spring Plungers	2.0	0.35	1.50	0.00		76.5	0
TSAT	Motor / Gearhead	25.0	0.80	4.00	0.00		71.4	0
TSAT	Fasteners / Spacers	45.0	0.00	0.00	0.00		78	0
TSAT	GlobalStar Patch Antenna	10.0	2.50	2.50	0.20		0	3

Note: Components are modeled as stainless steel unless otherwise noted in component name.

Section 8: Assessment for Tether Missions

ELaNa-5 CubeSats will not be deploying any tethers.

ELaNa-5 CubeSats satisfy requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 for the launch vehicle are addressed in ref. (g), and are not covered here.

If you have any questions, please contact the undersigned at

Appendix Index:

Appendix A. ELaNa-5 Component List by CubeSat: TSAT

Appendix A. ELaNa-5 Component List by CubeSat: TSAT

CubeSat	Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp (C)	Comment
TSAT	1	TSAT									Yes		Demises
TSAT	2	External Structure	External - Major	1	Aluminum 6061	Box	350	100	100	227	Yes		Demises
TSAT	3	GlobalStar Patch Antenna	External - Major	1	Ceramic	Square	10	25	25	2	No	1400	Compliant (3J) See **Error! Reference source not found.**
TSAT	4	Solar Panels	External - Major	4	Fiberglass	Panel	352	82	199	2.5	Yes		Demises
TSAT	5	Sep Switches	External - Minor	2	Steel / Gold	Round	8	4.5	10.5		No	1500	Demises See **Error! Reference source not found.**
TSAT	6	Plasma Probe	External - Minor	1	Fiberglass / Copper / Gold	Square	7.5	45	45	3	Yes		Demises
TSAT	7	Spring Plungers	External - Minor	2	Steel / Stainless Steel	Round	2	3.5	15		No	1500	Demises See **Error! Reference source not found.**
TSAT	8	Deployment Booms	External - Major	2	Kapton / Carbon Fiber	Flat Ribbon	30	4.5	2000	1	Yes		Demises
TSAT	9	Boom Sensor Head	External - Major	2	Copper	Tube	50	13	30		Yes		Demises
TSAT	10	End Plales	External - Major	2	Aluminum 6061	Square	150	100	100	2	Yes		Demises
TSAT	11	Batteries	Internal - Major	6	Aluminum Foil / Plastic / Lithium	Square	750	50	100	13	Yes		Demises
TSAT	12	Motor / Gearhead	Internal - Minor	1	Steel / Nickel / Copper / Iron	Round	25	8	40		No	1500	Demises See **Error! Reference source not found.**
TSAT	13	Comm Board	Internal - Minor	1	Fiberglass / Copper	Square	45	61	82	1.7	Yes		Demises
TSAT	14	GlobalStar Board	Internal - Minor	1	Fiberglass / Copper	Square	60	61	82	1.7	Yes		Demises
TSAT	15	Power Management Board	Internal - Minor	1	Fiberglass / Copper	Square	125	61	140	1.7	Yes		Demises
TSAT	16	Instrument Microcontroller Baord	Internal - Minor	1	Fiberglass / Copper	Square	45	61	82	1.7	Yes		Demises

TSAT	27	Instrument Baord	Internal - Minor	1	Fiberglass / Copper	Square	50	61	82	1.7	Yes		Demises
TSAT	18	Boom Reel Assembly	Internal - Minor	1	Carbon Fiber	Square	70	90	90	13	Yes		Demises
TSAT	19	Solid State Detector Assemby	Internal - Minor	1	Copper / Aluminum 6061	Square	75	19	50	19	Yes		Demises
TSAT	20	EMI Shield	Internal - Major	1	Aluminum 6061	Square	50	90	90	2	Yes		Demises
TSAT	21	Magnotometer	Internal - Minor	1	Fiberglass / Copper	Square	27	42	52	20	Yes		Demises
TSAT	22	Fasteners / Spacers	Internal - Minor		Stainless Steel / Aluminum		45				No	1500	Demises See **Error! Reference source not found.**
TSAT	23	Cabling	Internal - Minor		Copper alloy		50				Yes		Demises
TSAT	24	Damping	Iternal - Minor		MU-Metal	Rod	40	10	75		Yes		Demises